

BEE 2026 Exam Answer Key

Step-by-Step Solutions & Simplified Theory for End-Semester Exams

All sections are expanded by default for easy reading.

1. AC Fundamentals & Single Phase Circuits

Q1. Draw Impedance and Power triangles. Define Active, Reactive, and Apparent power.

6 Marks



Definitions & Units:

- **Active Power (P):** The actual power consumed by the circuit to do useful work (like heat or light).
Unit: Watt (W) or kW. **Formula:** $P = V \times I \times \cos\phi$
- **Reactive Power (Q):** The power that continuously bounces back and forth between the source and the reactive components (Inductor/Capacitor). It does no useful work.
Unit: VAR or kVAR. **Formula:** $Q = V \times I \times \sin\phi$
- **Apparent Power (S):** The total power supplied by the source. It is the vector sum of Active and Reactive power.
Unit: VA or kVA. **Formula:** $S = V \times I$

How to Draw the Triangles in Exam:

1. Impedance Triangle: Draw a right-angled triangle.

- Base = Resistance (R)
- Perpendicular = Reactance ($X = X_L - X_C$)

- Hypotenuse = Impedance (Z). Mark the angle φ between R and Z .

2. Power Triangle: Draw a similar right-angled triangle right below it.

- Base = Active Power (P)
- Perpendicular = Reactive Power (Q)
- Hypotenuse = Apparent Power (S). Mark the same angle φ between P and S .

Q2. Derive the RMS value of a sinusoidal current in terms of its peak value.

6 Marks



Definition: RMS (Root Mean Square) is the value of a steady DC current that produces the same amount of heat in a resistor as the AC current over the same time.

Step-by-Step Derivation:

Let the instantaneous alternating current be: $i = I_m \sin\theta$

According to the definition, we take the square of the current, find its mean (average) over a half cycle (0 to π), and then take the square root.

$$I_{\text{rms}} = \sqrt{\left[\frac{1}{\pi} \int_0^{\pi} i^2 d\theta \right]}$$

Substitute $i = I_m \sin\theta$:

$$I_{\text{rms}} = \sqrt{\left[\frac{1}{\pi} \int_0^{\pi} (I_m \sin\theta)^2 d\theta \right]}$$

$$I_{\text{rms}} = \sqrt{\left[\frac{I_m^2}{\pi} \int_0^{\pi} \sin^2\theta d\theta \right]}$$

Reason for next step:

We use the trigonometry identity $\sin^2\theta = (1 - \cos 2\theta) / 2$ to make integration easy.

$$I_{\text{rms}} = \sqrt{\left[\frac{I_m^2}{2\pi} \int_0^{\pi} (1 - \cos 2\theta) d\theta \right]}$$

Integrate:

$$I_{\text{rms}} = \sqrt{\left[\left(I_m^2 / 2\pi \right) \left[\theta - (\sin 2\theta / 2) \right]_0^\pi \right]}$$

Apply limits (0 to π). Note that $\sin(2\pi) = 0$ and $\sin(0) = 0$:

$$I_{\text{rms}} = \sqrt{\left[\left(I_m^2 / 2\pi \right) \left[(\pi - 0) - (0 - 0) \right] \right]}$$

$$I_{\text{rms}} = \sqrt{\left[\left(I_m^2 / 2\pi \right) \times \pi \right]}$$

$$I_{\text{rms}} = \sqrt{\left[I_m^2 / 2 \right]}$$

Final Answer:

$$I_{\text{rms}} = I_m / \sqrt{2} = 0.707 \times I_m$$

Q3. State the condition for resonance and define the Q-factor of a series RLC circuit.

4 Marks



Condition for Resonance:

Resonance occurs in a series RLC circuit when the Inductive Reactance (X_L) and Capacitive Reactance (X_C) are exactly equal. Because they are 180° out of phase, they cancel each other out.

- **Condition:** $X_L = X_C$
- **Result:** The total impedance becomes purely resistive ($Z = R$). The circuit draws maximum current, and the power factor becomes exactly 1 (Unity).

Q-Factor (Quality Factor):

The Q-factor is defined as the **voltage magnification** at resonance. It tells us how many times greater the voltage across the inductor (or capacitor) is compared to the supply voltage.

$$Q = (\text{Voltage across L or C}) / (\text{Supply Voltage})$$

$$Q = X_L / R \text{ or } X_C / R$$

$$Q = (1 / R) \times \sqrt{L / C}$$

Q4. Derive the expression for current drawn by a purely inductive circuit when $V_m \sin(\omega t)$ is applied.

6 Marks



Let the applied AC voltage be: $v = V_m \sin(\omega t)$

In a pure inductor (L), the voltage is always proportional to the rate of change of current. The fundamental formula is:

$$v = L \times (di / dt)$$

Step 1: Rearrange to solve for current (i)

$$\begin{aligned} V_m \sin(\omega t) &= L \times (di / dt) \\ di &= (V_m / L) \times \sin(\omega t) dt \end{aligned}$$

Step 2: Integrate both sides

$$\int di = \int (V_m / L) \sin(\omega t) dt$$

Reason:

The integral of $\sin(\omega t)$ is $-\cos(\omega t) / \omega$.

$$i = (V_m / \omega L) \times (-\cos(\omega t))$$

Step 3: Convert to Sine wave

Reason:

We know from trigonometry that $-\cos(\theta) = \sin(\theta - 90^\circ)$. Also, ωL is the Inductive Reactance (X_L).

$$i = (V_m / X_L) \times \sin(\omega t - 90^\circ)$$

Let $I_m = V_m / X_L$ (Peak Current)

$$i = I_m \sin(\omega t - 90^\circ)$$

Conclusion: The current lags the voltage by exactly 90° in a pure inductor.

2. Three-Phase Systems

Q5. Define: Balanced Load, Phase Sequence, and Symmetrical Supply System.

3 Marks



- **Balanced Load:** A 3-phase load where the impedance (resistance and reactance) in all three phases (R, Y, B) is exactly equal in magnitude and nature.
- **Phase Sequence:** The specific order in which the three phase voltages reach their maximum positive peak values. The standard sequence is $R \rightarrow Y \rightarrow B$.
- **Symmetrical Supply System:** A 3-phase system where all three voltages have equal magnitude (RMS value) and are exactly 120° electrical degrees apart from each other.

Q6. Prove that the phasor sum of three symmetrical phase EMFs (RYB) is equal to zero.

6 Marks



Let the three symmetrical phase EMFs be represented by standard sine waves, 120° apart:

$$e_R = E_m \sin(\omega t)$$

$$e_Y = E_m \sin(\omega t - 120^\circ)$$

$$e_B = E_m \sin(\omega t - 240^\circ)$$

Step 1: Add e_Y and e_B first using Trigonometry

Formula used:

$$\sin A + \sin B = 2 \sin((A+B)/2) \cos((A-B)/2)$$

$$e_Y + e_B = E_m [\sin(\omega t - 120^\circ) + \sin(\omega t - 240^\circ)]$$

$$\text{Here, } A = \omega t - 120^\circ \text{ and } B = \omega t - 240^\circ$$

$$(A+B)/2 = \omega t - 180^\circ$$

$$(A-B)/2 = 60^\circ$$

$$e_Y + e_B = E_m [2 \times \sin(\omega t - 180^\circ) \times \cos(60^\circ)]$$

Step 2: Simplify

Reason:

We know $\cos(60^\circ) = 0.5$, and $\sin(\theta - 180^\circ) = -\sin(\theta)$.

$$e_Y + e_B = E_m [2 \times (-\sin(\omega t)) \times 0.5]$$

$$e_Y + e_B = - E_m \sin(\omega t)$$

Step 3: Add e_R to the result

$$\text{Total Sum} = e_R + (e_Y + e_B)$$

$$\text{Total Sum} = E_m \sin(\omega t) + [- E_m \sin(\omega t)]$$

$$\text{Total Sum} = 0 \text{ (Hence Proved)}$$

Q7. Derive the relationship between Line and Phase Voltage for a Star connected load.

6 Marks



In a Star connection, the Line Voltage (V_L) is the vector difference between two Phase Voltages (V_{ph}).

$$V_L = V_R - V_Y \text{ (Vector Subtraction)}$$

Geometric Derivation:

1. Draw V_R and V_Y as two lines of equal length (V_{ph}) with a 120° angle between them.
2. To subtract V_Y , reverse its direction to get $-V_Y$. The angle between V_R and $-V_Y$ becomes 60° .
3. Draw the resultant V_L using the parallelogram law.
4. Draw a perpendicular bisector from the center to V_L . This splits V_L into two equal halves and splits the 60° angle into two 30° angles.

Mathematical Calculation:

Look at the right-angled triangle formed.

$$\cos(30^\circ) = (\text{Half of } V_L) / V_{ph}$$

$$(V_L / 2) = V_{ph} \times \cos(30^\circ)$$

Reason:

$$\text{We know } \cos(30^\circ) = \sqrt{3} / 2.$$

$$V_L / 2 = V_{ph} \times (\sqrt{3} / 2)$$

Cancel the 2 from both sides:

$$V_L = \sqrt{3} \times V_{ph}$$

Note: For Star connection, Line Current = Phase Current ($I_L = I_{ph}$) because the same wire carries both.

3. Transformers & DC Machines

Q8. List the various losses in a transformer and state where they occur.

3 Marks



Transformer losses are divided into two main categories:

1. **Iron Losses (Core Losses):** These occur in the magnetic steel core of the transformer. They are **constant** (do not change with load).
 - *Hysteresis Loss:* Due to continuous reversal of magnetization in the core.
 - *Eddy Current Loss:* Due to circulating currents induced inside the solid core.
2. **Copper Losses (I^2R Losses):** These occur in the copper windings (primary and secondary coils) due to their electrical resistance. They are **variable** (increase as the load current increases).

Q9. Derive the condition for maximum efficiency of a single-phase transformer.

6 Marks



Efficiency (η) = Output Power / Input Power = Output / (Output + Losses)

$$\eta = (V_2 I_2 \cos\phi_2) / (V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{eq})$$

Where P_i is constant Iron loss, and $I_2^2 R_{eq}$ is variable Copper loss (P_{cu}).

Step 1: Divide the numerator and denominator by I_2

$$\eta = (V_2 \cos\phi_2) / [V_2 \cos\phi_2 + (P_i / I_2) + I_2 R_{eq}]$$

Step 2: Condition for Maximum Efficiency

For efficiency to be maximum, the denominator must be minimum. To find the minimum value, we differentiate the denominator with respect to I_2 and set it to zero.

$$d/dI_2 [V_2 \cos\phi_2 + P_i I_2^{-1} + I_2 R_{eq}] = 0$$

$$0 + P_i (-1) I_2^{-2} + R_{eq} = 0$$

$$R_{eq} = P_i / I_2^2$$

$$I_2^2 R_{eq} = P_i$$

Final Conclusion:

Variable Copper Loss = Constant Iron Loss

Q10. Explain the necessity of a starter in a DC motor.

3 Marks



The current drawn by a DC motor armature is given by the formula:

$$I_a = (V - E_b) / R_a$$

Where V is supply voltage, E_b is Back EMF, and R_a is armature resistance.

- **At the time of starting:** The motor speed (N) is zero. Since Back EMF depends on speed ($E_b \propto N$), **$E_b = 0$** .

- Therefore, starting current $I_a = V / R_a$.

- **The Problem:**

The armature resistance (R_a) is extremely small (e.g., 0.5Ω). If V is 230V, the starting current will be $230 / 0.5 = \mathbf{460 \text{ Amps!}}$ This is dangerously high and will burn the motor windings.

- **The Solution (Starter):** A starter adds a heavy external resistance in series with the armature during starting to limit the current to a safe value. As the motor speeds up, E_b builds up, and the external resistance is gradually cut out.

4. Safety, Wiring & Appliances

Q11. Explain MCB, MCCB, ELCB and Compare Fuse with MCB.

8 Marks



1. MCB (Miniature Circuit Breaker): An electromechanical switch that automatically trips (opens the circuit) to protect wires from Overload (too many appliances) and Short Circuits. It can be manually reset after the fault is cleared.

2. MCCB (Molded Case Circuit Breaker): Works exactly like an MCB but is built for heavy industrial use. It can handle very high currents (up to 2500A) and has adjustable trip settings.

3. ELCB / RCCB (Earth Leakage Circuit Breaker): Designed specifically to protect humans from fatal electric shocks. It constantly monitors the current going in (Phase) and coming out (Neutral). If there is a difference (meaning current is leaking through a person to the ground), it trips in milliseconds.

Comparison: Fuse vs. MCB

Feature	Fuse	MCB
Working Principle	Melts a wire due to heat.	Electromagnetic tripping mechanism.

After Fault	Must be replaced (wasteful).	Just flip the switch to reset (reusable).
Speed & Safety	Slower, less sensitive.	Very fast, highly sensitive, safer.

Q12. What is Earthing? Why is it necessary?

8 Marks



Definition: Earthing (or Grounding) means connecting the non-current-carrying metal parts of electrical equipment (like the outer body of a motor, geyser, or iron) to the deep earth (soil) using a thick conducting wire. The earth is considered to be at 0 Volts.

Why is it Necessary? (Advantages):

- **Protects Human Life:** If internal insulation fails and the live phase wire touches the metal body, the body becomes live (230V). If a human touches it, they get a fatal shock. Earthing provides a low-resistance path for the fault current to flow directly into the ground, blowing the fuse and keeping the human safe.
- **Protects Equipment:** Safeguards appliances from voltage surges caused by lightning strikes or accidental contact with high-voltage transmission lines.
- **Ensures Voltage Stability:** Keeps the system voltage stable relative to the ground.

5. 2026 Guaranteed Numericals (Step-by-Step)

Prediction 1: Single-Phase Series RLC Circuit Numerical

6 Marks



Expected Question: A series circuit has $R=10\Omega$, $L=0.1H$, and $C=150\mu F$ connected to a 230V, 50Hz supply. Calculate Impedance, Current, Power Factor, Active Power, and Reactive Power.

Step 1: Write Given Data

$R = 10\ \Omega$, $L = 0.1\ \text{H}$, $C = 150 \times 10^{-6}\ \text{F}$, $V = 230\ \text{V}$, $f = 50\ \text{Hz}$

Step 2: Calculate Reactances (X_L and X_C)

Reason:

Inductors and capacitors oppose AC current. We must find their exact opposition values.

$$X_L = 2\pi fL = 2 \times 3.1416 \times 50 \times 0.1 = \mathbf{31.42\ \Omega}$$

$$X_C = 1 / (2\pi fC) = 1 / (2 \times 3.1416 \times 50 \times 150 \times 10^{-6}) = \mathbf{21.22\ \Omega}$$

Step 3: Calculate Total Impedance (Z)

Reason:

Impedance is the total opposition of the circuit, combining resistance and net reactance using the Pythagoras theorem.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$Z = \sqrt{10^2 + (31.42 - 21.22)^2}$$

$$Z = \sqrt{100 + (10.2)^2} = \sqrt{100 + 104.04} = \sqrt{204.04}$$

$$\mathbf{Z = 14.28\ \Omega}$$

Step 4: Calculate Current (I) & Power Factor (cos ϕ)

$$I = V / Z = 230 / 14.28 = \mathbf{16.10\ \text{A}}$$

$$\cos\phi = R / Z = 10 / 14.28 = \mathbf{0.70}$$

*(Since $X_L > X_C$, the circuit is inductive, so Power Factor is **Lagging**)*

Step 5: Calculate Powers (P and Q)

$$\text{Active Power (P)} = V \times I \times \cos\phi = 230 \times 16.10 \times 0.70 = 2592.1 \text{ W (or 2.59 kW)}$$

$$\text{Reactive Power (Q)} = V \times I \times \sin\phi$$

Reason:

$$\text{If } \cos\phi = 0.70, \text{ then } \sin\phi = \sqrt{1 - 0.70^2} = 0.714$$

$$Q = 230 \times 16.10 \times 0.714 = 2645.5 \text{ VAR}$$

Prediction 2: Three-Phase Star Connected Numerical

6 Marks



Expected Question: Three identical impedances of $Z = (8 + j6) \Omega$ are connected in Star across a 3-phase, 400V, 50Hz supply. Calculate Phase Voltage, Phase Current, Line Current, and Total Power.

Step 1: Analyze the Impedance (Z)

$Z = 8 + j6$ means Resistance (R) = 8Ω and Reactance (X) = 6Ω .

$$\text{Magnitude } |Z| = \sqrt{R^2 + X^2} = \sqrt{8^2 + 6^2} = \sqrt{64 + 36} = \sqrt{100} = 10 \Omega$$

$$\text{Power Factor } (\cos\phi) = R / |Z| = 8 / 10 = 0.8 \text{ (Lagging)}$$

Step 2: Apply Star Connection Rules

Rule:

In a Star connection, Line Voltage is $\sqrt{3}$ times Phase Voltage, but Line Current equals Phase Current.

Given Line Voltage (V_L) = 400 V

Phase Voltage (V_{ph}) = $V_L / \sqrt{3} = 400 / 1.732 = 230.94 \text{ V}$

Step 3: Calculate Currents

Phase Current (I_{ph}) = $V_{ph} / |Z| = 230.94 / 10 = 23.09 \text{ A}$

Line Current (I_L) = $I_{ph} = 23.09 \text{ A}$

Step 4: Calculate Total 3-Phase Active Power

Total Power (P) = $\sqrt{3} \times V_L \times I_L \times \cos\phi$

$P = 1.732 \times 400 \times 23.09 \times 0.8$

$P = 12,801 \text{ Watts (or 12.8 kW)}$

Prediction 3: Transformer Efficiency Numerical

6 Marks



Expected Question: A 40 kVA transformer has Full-Load Copper Loss = 800W and Iron Loss = 400W. Find: (i) Efficiency at Full Load, 0.8 pf. (ii) Efficiency at Half Load, Unity pf. (iii) kVA at Max Efficiency.

Given Data: Rating = 40 kVA, $P_{cu(fl)} = 800 \text{ W}$, $P_i = 400 \text{ W}$.

Note: Iron loss (P_i) is ALWAYS constant. Copper loss changes with load.

Case (i): Full Load ($x=1$), 0.8 p.f.

$$\text{Output Power} = \text{kVA} \times \cos\phi = 40 \times 0.8 = 32 \text{ kW} = 32,000 \text{ W}$$

$$\text{Total Losses} = P_i + P_{\text{Cu(fl)}} = 400 + 800 = 1,200 \text{ W}$$

$$\text{Input Power} = \text{Output} + \text{Losses} = 32,000 + 1,200 = 33,200 \text{ W}$$

$$\text{Efficiency } (\eta) = (\text{Output} / \text{Input}) \times 100$$

$$\eta = (32,000 / 33,200) \times 100 = \mathbf{96.38\%}$$

Case (ii): Half Load ($x=0.5$), Unity p.f. ($\cos\phi = 1$)

Reason:

Copper loss at any load 'x' is calculated as: $x^2 \times \text{Full Load Cu Loss}$.

$$\text{Output Power} = (x \times \text{kVA}) \times \cos\phi = (0.5 \times 40) \times 1 = 20 \text{ kW} = 20,000 \text{ W}$$

$$\text{Cu Loss at Half Load} = (0.5)^2 \times 800 = 0.25 \times 800 = 200 \text{ W}$$

$$\text{Total Losses} = P_i + P_{\text{Cu(half)}} = 400 + 200 = 600 \text{ W}$$

$$\text{Input Power} = 20,000 + 600 = 20,600 \text{ W}$$

$$\eta = (20,000 / 20,600) \times 100 = \mathbf{97.08\%}$$

Case (iii): kVA at Maximum Efficiency

Condition:

Max efficiency happens when Variable Loss (Cu) = Constant Loss (Iron).

$$x^2 \times P_{\text{Cu(fl)}} = P_i$$

$$x^2 \times 800 = 400 \Rightarrow x^2 = 400 / 800 = 0.5$$

$$x = \sqrt{0.5} = 0.707 \text{ (This means max efficiency occurs at 70.7\% of full load)}$$

kVA at max η = x $\times$ Full Load kVA

kVA = 0.707 $\times$ 40 = **28.28 kVA**